

## **Chapter 7**

# **Dissolved Oxygen Monitoring in the Stockton Ship Channel, 2001-2002**

### **Introduction**

Dissolved oxygen levels in the Stockton Ship Channel have been monitored by the Department of Water Resources (DWR) during the late summer and fall of each year since 1968. Due to a variety of factors, dissolved oxygen levels have historically dropped to 5.0 mg/L or less in the central and eastern portions of the channel. These factors include low San Joaquin River inflows, warm water temperatures, high biochemical oxygen demand (BOD), reduced tidal circulation, and intermittent reverse flows in the San Joaquin River past Stockton.

Because low dissolved oxygen levels can have adverse impacts on fisheries and other beneficial uses of the waters within the Bay-Delta, California has established specific water quality objectives to protect these uses. Within the channel, two separate dissolved oxygen objectives have been established. The most recent basin plan of the Central Valley Regional Water Quality Control Board (CVRWQCB 1998) establishes a baseline objective of 5.0 mg/L for the entire Delta, including the Stockton Ship Channel. However, due to the special concerns in the Stockton Ship Channel, a dissolved oxygen objective of 6.0 mg/L has been established in the channel for September through November by the State Water Resources Control Board (SWRCB 1995). This objective was established to protect fall-run Chinook salmon, and applies to the San Joaquin River between Stockton and the Turner Cut, which includes the eastern channel. Because a significant portion of the study area is within the designated 6.0 mg/L objective area and the majority of the study occurs within the September through November time frame, this report evaluates the data using the 6.0 mg/L objective.

As part of a 1969 Memorandum of Understanding between DWR, the US Fish and Wildlife Service (USFWS), the US Bureau of Reclamation (USBR), and the Department of Fish and Game (DFG), DWR has installed a rock barrier across the upstream end of Old River in the fall when San Joaquin River outflows are low. This Head of Old River Barrier (Barrier) increases net flows down the San Joaquin River past Stockton. The higher flows can help increase dissolved oxygen concentrations within the channel. Because of bank erosion and barrier overtopping concerns, the Barrier is usually installed when average daily San Joaquin River flows past Vernalis are projected to be approximately 2,000 cfs or less.

DWR installed the Barrier on October 6, 2001, and October 4, 2002, because late summer San Joaquin River flows past Vernalis were low (average September daily San Joaquin River flows past Vernalis were 1,390 cfs in 2001 and 1,160 cfs in 2002), and early fall flows were not projected to be sufficient to alleviate dissolved oxygen concerns in the eastern channel. The Barrier was removed in 2001 on November 30, and in 2002 on November 15, due to a sustained improvement in dissolved oxygen conditions, and concern

for potential bank erosion and barrier overtopping due to projected high, late fall flows. This report summarizes monitoring results during fall 2001 and 2002 when the Barrier was in place.

## Methods

Monitoring of dissolved oxygen concentrations in the Stockton Ship Channel was conducted by vessel seven times between August 1 and December 5, 2001, and nine monitoring runs were conducted from July 23 to December 18, 2002. During each of the monitoring runs, fourteen sites were sampled at low water slack, beginning at Prisoners Point (Station 1) in the central Delta and ending at the Stockton Turning Basin at the terminus of the ship channel (Station 14). For geographic reference and simplifying reporting, the sampling stations are keyed to channel light markers<sup>1</sup> as shown in Figure 7-1.

Because monitoring results differ along the channel<sup>2</sup>, sampling stations are grouped into western, central, and eastern regions within the channel, and these regions are highlighted in Figure 7-1. The western channel begins at Prisoners Point (Station 1) and ends at Light 14 (Station 5). The central channel begins at Light 18 (Station 6) and ends at Light 34 (Station 9). Finally, the eastern channel begins at Light 40 (Station 10) and ends at Light 48 (Station 13). The Turning Basin (Station 14) is unique within the channel because it is east of the entry point of the San Joaquin River into the channel and therefore forms a backwater relatively isolated from river flow. Because of the unique hydro-morphology of Station 14, the findings for this station are discussed separately from those of the other channel stations.

Discrete samples were taken from the top (1 meter from surface) and bottom (1 meter from bottom) of the water column at each station at low water slack tide, and analyzed for dissolved oxygen concentrations and temperature. Top dissolved oxygen samples were analyzed with the modified Winkler titration method (APHA 1998). Bottom dissolved oxygen samples were measured using either a YSI polarographic electrode (Model No. 5739) with a Seabird CTD 911+ data logger, or with a YSI 6600 sonde equipped with a Model #6562 dissolved oxygen sensor. The multiple methods used to measure surface and bottom dissolved oxygen levels provided a means to compare various instruments and their accuracy. Surface and bottom water temperatures were measured using a YSI 6600 sonde equipped with a Model No. 6560 thermistor temperature probe or a Seabird SBE3 temperature probe.

Flow data for the San Joaquin River at Vernalis were obtained from station data at Vernalis, which was compiled by DWR<sup>3</sup>. Average daily flows past Vernalis were obtained by averaging 15-minute data for a daily average flow



**Figure 7-1 Monitoring sites in the Stockton Ship Channel**

<sup>1</sup> Channel light markers are ship navigational aids placed in navigable waters. Although they are not spaced at fixed intervals, they provide convenient landmarks for identifying sample locations.

<sup>2</sup> The findings of previous fall studies have shown that fall dissolved oxygen levels are typically robust and high (7.0-9.0 mg/L) in the western channel; transitional, variable (4.0-7.0 mg/L), and stratified in the central channel; and low (3.0-5.0 mg/L) and stratified in the eastern channel.

<sup>3</sup> Station information: DWR Station SJR at Vernalis, RSAN112

rate. Tidal cycles of ebb and flood are not significant in flows at Vernalis, and flow is always downstream (positive). Flows of the San Joaquin River past Stockton used in this report were obtained from data recorded by the US Geological Survey flow-monitoring station southeast of Rough and Ready Island<sup>4</sup>.

Flow rates in the San Joaquin River at Stockton are heavily influenced by tidal action, with daily ebb and flood tidal flows of 3,000 cfs or greater in either direction. To calculate net daily flows, the tidal pulse is removed from the USGS 15-minute flow data with a Butterworth filter<sup>5</sup> to yield net daily flow. Due to low flows at Vernalis, local agricultural diversions, and export pumping, net daily flows at Stockton can sometimes reverse direction, which results in a net upstream flow. Net daily reverse flows at Stockton were seen briefly in December 2001, but not seen during the fall 2002 study period.

In this report, we refer to dissolved oxygen “sags” and “depressions”. We define a dissolved oxygen “sag” as a region within the channel where dissolved oxygen levels are < 5.0 mg/L. These levels do not meet the CVRWQCB objectives described in the introduction to this chapter. A dissolved oxygen “depression” is defined as a region within the channel where dissolved oxygen levels are  $\geq 5.0$  mg/L but < 6.0 mg/L. These levels also do not meet the SWRCB objective for September through November.

## Results

During summer and fall 2001 and 2002, dissolved oxygen levels varied considerably between regions within the channel. In both years, dissolved oxygen concentrations in the western channel were relatively high and stable and ranged from 6.6 to 10.0 mg/L through July and December. The robustness of dissolved oxygen concentrations in the western channel is apparently due to the greater tidal mixing, the absence of conditions creating BOD, and shorter hydrological residence time than in other sections of the channel. In the central portion of the channel, dissolved oxygen concentrations dropped from the consistently high concentrations in the western channel to concentrations below 5.0 mg/L through much of August, September, and October in 2001 and September through October in 2002. In the eastern channel, the dissolved oxygen levels were low from August through October 2001 and August through September 2002. The eastern channel dissolved oxygen levels tended to be stratified and were more variable in October. In 2001, dissolved oxygen levels in the eastern channel ranged from a low of 3.7 mg/L to a high of 10.5 mg/L. In 2002 levels ranged from 3.3 mg/L to 10.8 mg/L. Changing inflows into the eastern channel may partially account for the variability in dissolved oxygen levels observed here.

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<sup>4</sup> Station information: USGS 304810 SJR at Stockton, RSAN063.

<sup>5</sup> The USGS uses a Butterworth bandpass filter to remove frequencies (tidal cycles) from 15-minute flow data, that occur during less than a 30-hour period. The resulting 15-minute time-series is then averaged to provide a single daily value that represents net river flow exclusive of tidal cycles.

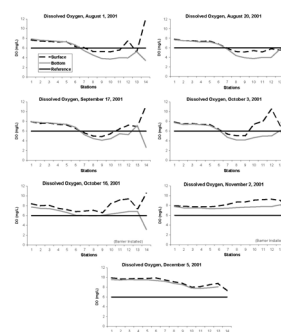
## Dissolved Oxygen Levels in 2001

On August 1, a surface dissolved oxygen depression and a bottom dissolved oxygen sag were observed in the central and eastern channels (Figure 7-2). Bottom dissolved oxygen levels dropped to a low of 3.7 mg/L at Station 10. In the eastern channel and part of the central channel (Stations 8 through 12), marked vertical dissolved oxygen stratification occurred, with bottom dissolved oxygen levels approximately 2.0 to 3.0 mg/L less than surface levels. Dissolved oxygen levels remained low on August 20 as the bottom dissolved oxygen sag within the central channel and the stratification within the eastern channel continued. Relatively warm late summer water temperatures (22.1-26.3 °C) (Figure 7-3) and low San Joaquin River inflows into the channel east of Rough and Ready Island appear to have contributed to the low dissolved oxygen concentrations observed. Average net daily flows in the San Joaquin River past Vernalis in August ranged from 1,253 to 1,531 cfs (Figure 7-4). USGS flow data were not available for San Joaquin flows past Stockton for this period.

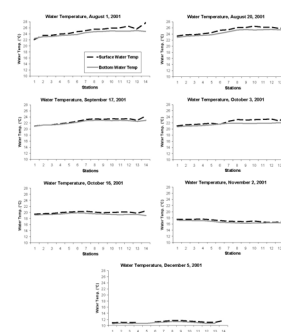
The extent of the surface depression and the bottom sag present in the channel in August decreased slightly in September. On September 17, eastern and central channels showed depressed surface dissolved oxygen concentrations ranging from 4.9 to 5.7 mg/L (Figure 7-2). At the bottom, low dissolved oxygen levels continued, with levels ranging from 4.1 to 4.5 mg/L. The stratification between surface and bottom values decreased to 0.5 to 1.0 mg/L. Average September water temperatures of 21 to 24 °C within the channel were significantly cooler (3 °C) than August water temperatures (Figure 7-3). September flow conditions within the San Joaquin River past Vernalis did not improve, and ranged from 1,255 to 1,580 cfs. USGS flow data for San Joaquin River at Stockton in September showed flows ranged from 1,037 to 735 cfs (Figure 7-4).

A gradual but sustained improvement of dissolved oxygen conditions within the channel occurred in October. Initial sampling on October 3 showed continuation of the dissolved oxygen sag within the central and eastern channel with bottom levels ranging from 4.2 to 5.0 mg/L (Figure 7-2). A dissolved oxygen depression of 5.1 to 5.4 mg/L persisted at the surface of the central channel. These low dissolved oxygen levels can be attributed in part to sustained warm water temperatures (21-24 °C) (Figure 7-3) and relatively low flow conditions past Stockton in early October. Incomplete flow data recorded by USGS shows average daily flows past Stockton ranged from 1,370 to 1,589 cfs through October 15. During this period, the average net daily San Joaquin River flow past Vernalis ranged from 1,300 to 1,641 cfs (Figure 7-4).

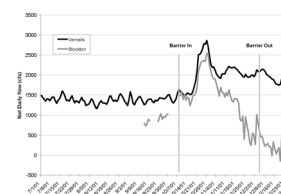
By October 16, dissolved oxygen conditions throughout the channel had improved significantly. Surface dissolved oxygen concentrations throughout the channel were all greater than 6.0 mg/L (Figure 7-2). However, a slight bottom dissolved oxygen depression, at 5.9 mg/L, persisted in the central channel. The general increase in dissolved oxygen levels throughout the channel may be attributed to significantly decreased water temperatures and improved inflows. Water temperatures (19-20 °C) were approximately 2 to 3 degrees cooler than temperatures recorded on October 3 (Figure 7-3). Flow conditions past Stockton from October 16 through 31 ranged from 1,234 to



**Figure 7-2 Dissolved oxygen levels, Aug 1-Dec 5, 2001**



**Figure 7-3 Surface and bottom water temperatures, Aug 1-Dec 5, 2001**



**Figure 7-4 Average net daily flows in the San Joaquin River at Stockton and Vernalis, Jul 1-Dec 30, 2001**

2,541 cfs. This improvement was due, in part, to the placement of the Barrier on October 6, 2002. Average daily San Joaquin River flows past Vernalis from October 16 through October 31 ranged from 1,509 to 2,861 cfs (Figure 7-4).

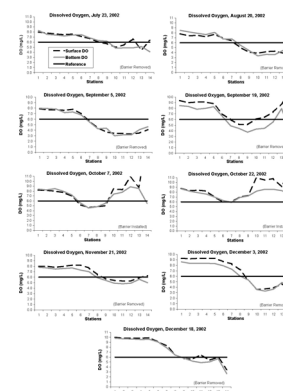
Monitoring on November 2 confirmed a sustained improvement of dissolved oxygen levels throughout the channel. Surface dissolved oxygen levels ranged from 7.8 to 9.3 mg/L and bottom levels ranged from 7.5 to 8.1 mg/L (Figure 7-2). Water temperatures (16-17 °C) were 2 to 3 degrees cooler than those measured in mid-October (Figure 7-3). The relatively high San Joaquin River flows past Vernalis were sustained in November, as average daily flows ranged from 1,917 to 2,216 cfs. However, flow rates past Stockton dropped dramatically, ranging from 1,964 cfs at the beginning of the month to 245 cfs at the end of November (Figure 7-4).

Although the Barrier was removed on November 30, high dissolved oxygen concentrations persisted in early December; all surface concentrations were above 8.0 mg/L and all bottom concentrations were above 7.0 mg/L (Figure 7-2). Water temperatures continued to drop from the levels measured in November, and ranged from 10 to 11 °C (Figure 7-3). Average daily flows past Stockton remained below 480 cfs for most of the month except for a large spike in flow during the last three days of December, after sampling was completed. Average net flow rates at Stockton reversed several times in December with the lowest flow rate recorded as -172 cfs on December 20. Average net daily flows past Vernalis were relatively constant and ranged from 1,956 to 2,082 cfs during this period (Figure 7-4). The cooler water temperatures, maintenance of relatively high San Joaquin River inflows, and the elimination of reverse flow conditions past Stockton apparently maintained the improved dissolved oxygen concentrations detected previously throughout the channel. Because of the sustained improvement, no further special studies were conducted for dissolved oxygen in 2001.

Highly stratified dissolved oxygen conditions were detected in the Stockton Turning Basin (Station 14) throughout much of fall 2001. Sampling on August 1, August 20, September 17, October 3, and October 16 showed surface dissolved oxygen concentrations ranging from 7.6 to 12.2 mg/L, and bottom dissolved oxygen concentrations ranging from 2.4 to 4.3 mg/L (Figure 7-2). Sampling on November 2 and December 5 showed that marked dissolved oxygen stratification had subsided, with surface and bottom dissolved oxygen concentrations ranging from 6.0 to 8.0 mg/L.

## Dissolved Oxygen Levels in 2002

Monitoring on July 23 showed that dissolved oxygen levels in the western channel were robust at  $\geq 7.5$  mg/L from Stations 1 to 5, with tidal mixing resulting on little stratification between surface and bottom measurements (Figure 7-5). Although dissolved oxygen levels remained largely unstratified in the central channel, dissolved oxygen levels decreased eastward. Dissolved oxygen levels ranged from a high of 7.5 mg/L at the bottom at Station 6 to a low of 5.7 mg/L at the surface at Station 9. Dissolved oxygen stratification was found in the eastern channel, with bottom levels at approximately 0.5 to 1.0 mg/L less than surface levels. As a result, a dissolved oxygen sag was present along the bottom at Stations 10 through 12



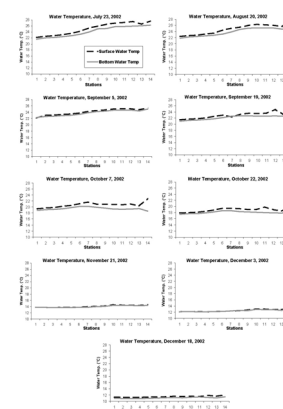
**Figure 7-5 Surface and bottom dissolved oxygen, Jul 23–Dec 18, 2002**

with a minimum dissolved oxygen value of 4.8 mg/L measured at Station 10. Surface measurements within the eastern channel were variable and ranged from 4.5 mg/L at Station 13 to 6.6 mg/L at Station 12. Thus, a surface dissolved oxygen depression was also present within the eastern channel. Relatively warm late summer water temperatures (22-27 °C) and low San Joaquin River inflows into the channel east of Rough and Ready Island appear to have contributed to the low dissolved oxygen concentrations in the eastern channel (Figure 7-6). Average daily flows in the San Joaquin River past Vernalis in July ranged from 1,186 to 1,426 cfs. Net flow in the San Joaquin River past Stockton ranged from 177 to 781 cfs (Figure 7-7).

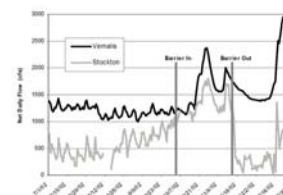
The surface depression and the bottom sag detected in the eastern channel in July intensified in August, and the dissolved oxygen sag extended into portions of the central channel (Figure 7-5). On August 20, Stations 8 and 9 in the central channel showed surface sag concentrations of 5.0 and 4.1 mg/L respectively. Stations 10 through 13 within the eastern channel also had low surface concentrations ranging from 3.9 to 5.0 mg/L. At the bottom of the channel, the dissolved oxygen sag persisted and included Station 9 (4.4 mg/L) in the central channel along with Stations 10 through 13 in the eastern channel (3.3-4.5 mg/L). The stratification between surface and bottom values remained low at approximately 0.5 to 1.0 mg/L. August water temperatures (22-26 °C) decreased slightly from July water temperatures within the channel (Figure 7-6). August flows in the San Joaquin River at Vernalis were similar to those of July, and ranged from 1,026 to 1,313 cfs. Net flow conditions past Stockton ranged from 114 to 849 cfs (Figure 7-7).

The dissolved oxygen sag detected previously within the channel intensified at both the surface and the bottom in early September as the area expanded westward on September 5 to Station 8 in the central channel and eastward to Station 14 (Turning Basin) (Figure 7-5). Within this extended sag area, a minimum surface measurement of 3.0 mg/L was detected at Station 10, and a minimum bottom measurement of 3.3 mg/L was detected at Station 12. In addition, a surface and bottom depression extended to Station 7 in the central channel where surface and bottom concentrations of 5.6 mg/L and 5.5 mg/L respectively were measured.

By September 19, stratified dissolved oxygen conditions became well established within the central and eastern portions of the channel, as bottom dissolved oxygen levels were generally 2.0 mg/L less than surface levels within these regions. In addition, the dissolved oxygen sag area that had originated within the eastern portion of the channel moved westward into the central channel. There, bottom dissolved oxygen concentrations ranged from 3.7 to 4.9 mg/L between Stations 7 and 9 and surface dissolved oxygen levels at these stations ranged from 5.1 to 6.0 mg/L. In contrast, surface dissolved oxygen conditions at all stations within the eastern channel improved significantly to greater than 6.0 mg/L. Bottom dissolved oxygen levels in the eastern channel were variable and ranged from a high of 7.9 mg/L at Station 13 to a low of 4.3 mg/L at Station 10. The slight improvement in dissolved oxygen conditions was possibly due, in part, to slightly cooler water temperatures and improved flow conditions within the channel. Late September water temperatures ranged from 21 to 24 °C, and were slightly cooler than August water temperatures in the channel (Figure 7-6). The



**Figure 7-6 Surface and bottom water temperatures, Jul 23–Dec 18, 2002**



**Figure 7-7 Net daily flow on Average daily flows in the San Joaquin River at Vernalis and Stockton, Jul 1–Dec 30, 2002**

average daily San Joaquin River flows at Vernalis in September were similar to those of July and August, and ranged from 1,000 to 1,326 cfs (Figure 7-7). However, net daily flows past Stockton in September increased steadily and ranged from 512 to 1,017 cfs.

Dissolved oxygen levels in the eastern channel improved significantly in October as surface levels at all stations were  $\geq 8.3$  mg/L on October 7 and  $\geq 9.0$  mg/L on October 22 (Figure 7-5). Bottom dissolved oxygen levels within the eastern channel were also high at  $\geq 7.4$  mg/L on October 7 and  $\geq 8.6$  mg/L on October 22. This improvement coincided with the placement of the Barrier on October 4, and an early fall storm that increased average daily San Joaquin River flows past Vernalis from 1,200 cfs in early October to 2,400 cfs by late October. Cooler water temperatures (19-20 °C) may have also contributed to improved dissolved oxygen concentrations within the eastern channel (Figure 7-6).

Increased inflows to the channel may have contributed to the relocation of the sag area westward from the eastern channel into the central channel in early October. Sampling on October 7 showed that surface and bottom dissolved oxygen levels within the central channel at Stations 7 and 8 ranged from 4.6 to 4.8 mg/L. By October 22, sag conditions had disappeared from the channel, as daily San Joaquin River flows past Vernalis in the latter half of the month averaged 1,900 cfs and cooler water temperatures (18-19 °C) prevailed. Net daily flows past Stockton in October ranged from 904 to 1,788 cfs (Figure 7-7).

Due to the increased dissolved oxygen levels in late October the Barrier was removed on November 15. This removal coincided with a return of dissolved oxygen sag conditions in the eastern channel from Stations 10 to 12 and bottom dissolved oxygen levels ranged from 4.8 to 4.9 mg/L (Figure 7-5). A surface depression was present throughout the eastern channel with values ranging from a low at Station 10 of 5.4 mg/L and a high at Station 13 of 5.9 mg/L. The central portion of the channel showed sustained improvement as only Station 9 had slight surface and bottom dissolved oxygen depressions of 5.7 and 5.4 mg/L, respectively.

Decreased inflows to the channel may have contributed to the return of sag conditions within the eastern channel in November. Net flows past Stockton were high in early November one week prior to removal of the Barrier, but dropped dramatically from a high of 1,687 cfs to a low of 49 cfs one week after the Barrier was removed. Although flows at Vernalis remained between 1,400 and 3,000 cfs for the remainder of the year, net flows past Stockton remained below 500 cfs with the exception of a brief pulse flow and moderate increase in mid-December (Figure 7-7). Cooler water temperatures (13.7-14.6 °C) in late November were apparently insufficient to compensate for reduced inflows to the channel (Figure 7-6).

The relatively low inflow conditions to the eastern channel continued as the net daily San Joaquin River flow past Stockton through December generally ranged from 9 to 836 cfs, with a one-day pulse flow of 1,340 cfs on December 17, 1002 (Figure 7-4). On December 3, dissolved oxygen values in the eastern channel were exceptionally low, ranging from 3.6 mg/L at

Station 10 to 4.6 mg/L at Station 13 at the surface, and 3.3 mg/L at Station 11 to 4.9 mg/L at Station 13 at the bottom (Figure 7-5). This sag occurred in spite of relatively cool water temperatures of 12.9 to 13.0 °C within this region (Figure 7-6). Dissolved oxygen conditions in the central channel were similar to those measured in late November, with a surface and bottom dissolved oxygen depression present only at Station 9.

Improved net San Joaquin River inflows past Stockton in late December and cooler water temperatures (11.3-12.8 °C) may have contributed to the slightly improved dissolved oxygen conditions detected within the eastern channel on December 18. Dissolved oxygen levels in the eastern channel stations increased by an average of 2.0 mg/L over surface and bottom dissolved oxygen concentrations measured in early December. However, a bottom dissolved oxygen sag of 4.9 mg/L was detected at Station 11 and depressed dissolved oxygen conditions were present at the surface and bottom of the remaining stations, with the exception of the surface measurement of 6.5 mg/L at Station 11. The gradual improvement coincided with cooler water temperatures (11.1-11.6 °C) in the eastern channel. Dissolved oxygen conditions in the central and western portions of the channel were well mixed (unstratified) and were exceptionally high ( $\geq 9.6$  mg/L) throughout the western channel. Because of the improving conditions, the 2002 dissolved oxygen special studies were terminated on December 18.

Highly stratified dissolved oxygen conditions were detected in the Stockton Turning Basin (Station 14) throughout much of fall 2002 (Figure 7-5). Sampling on August 20, September 19, October 7, and October 22 showed surface dissolved oxygen concentrations ranging from 9.6 to 18.1 mg/L, and bottom dissolved oxygen concentrations ranging from 3.4 to 7.6 mg/L. Sampling on September 5 indicated that the marked vertical stratification (9.6 mg/L at the surface and 3.4 mg/L at the bottom) detected on August 22 had subsided, as surface and bottom dissolved oxygen concentrations, at 4.1 and 4.6 mg/L, respectively, were similar. Sampling on November 21 indicated that a second and more sustained (late September through October) period of vertical stratification had subsided, with surface and bottom dissolved oxygen concentrations of 6.3 and 5.0 mg/L respectively. Sampling on December 3rd and 18 showed that dissolved oxygen stratification had subsided as all surface and bottom dissolved oxygen measurements were  $< 4.0$  mg/L and were within 1.0 mg/L of each other.

The periodic dissolved oxygen stratification appears to be the result of localized biological and water quality conditions occurring in the Turning Basin. The Basin is at the eastern dead-end terminus of the Stockton Ship Channel and is subject to reduced tidal activity, restricted water circulation, and increased residence times when compared to the remainder of the channel. As a result, water quality and biological conditions within the Basin have historically differed from those within the main downstream channel, and have led to extensive late summer and fall algal blooms and die-offs. The late summer and early fall of 2002 were no exception, as intense algal blooms composed primarily of green algae, flagellates, diatoms, and Cryptomonads were detected.



Stratified dissolved oxygen conditions often occur in the water column as a result of these blooms. At the surface, these blooms are highly productive and can produce markedly high surface dissolved oxygen levels. However, dead or dying bloom algae can sink to the bottom to contribute to high biochemical oxygen demand and low bottom dissolved oxygen levels. Bottom dissolved oxygen levels in the basin are further degraded by additional biochemical oxygen demand loadings in the area from sources such as regulated discharges into the San Joaquin River and non-point pollution adjacent to the basin. When bloom activity subsides, the dissolved oxygen stratification is reduced, and basin surface and bottom dissolved oxygen levels become less stratified.

## Summary

Dissolved oxygen concentrations in the eastern Stockton Ship Channel consistently fell below both the 5.0 mg/L and 6.0 mg/L objectives in both 2001 and 2002 due, in part, to relatively low net flows in the San Joaquin River past Stockton and to warm water temperatures. To alleviate low dissolved oxygen levels, a temporary Barrier across the head of Old River was installed in October of both years to increase flows down the main channel of the San Joaquin River into the channel.

In 2001, dissolved oxygen levels throughout the channel remained at greater than 6.0 mg/L after mid-October due to cooler water temperatures and improved inflows. However, in 2002, dissolved oxygen levels dropped below 6.0 mg/L in the eastern channel on November 21, and dropped further, to less than 4.0 mg/L in much of the eastern channel, on December 3. The removal of the Barrier on November 15, 2002, contributed to reduced net flows past Stockton, and likely contributed to low dissolved oxygen levels in late fall 2002 .

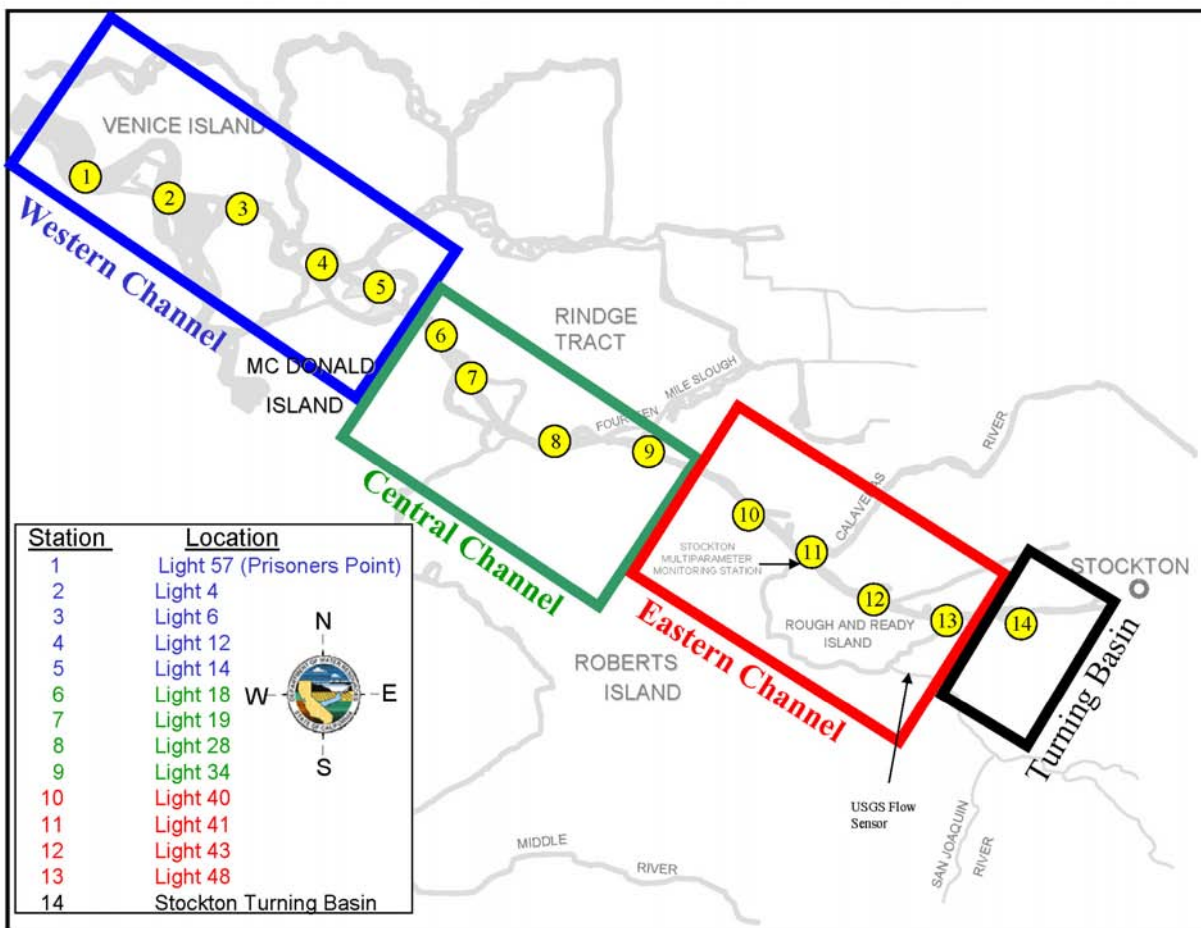
Dissolved oxygen conditions improved slightly on December 18, 2002, with surface dissolved oxygen levels greater than 6.0 mg/L in much of the eastern channel, and bottom dissolved oxygen values in the eastern channel greater than 5.0 mg/L. Significantly cooler water temperatures (11.3-12.8 °C) along with a moderate increase in net daily San Joaquin River flows past Stockton in December appear to have ultimately contributed to sustained improvement of dissolved oxygen conditions.

## References

- [APHA] American Public Health Association. 1998. *Standard Methods for the Examination of Water and Wastewater*. 20th Edition. Washington, D.C.
- [CVRWQCB] Central Valley Regional Water Quality Control Board. 1998. *Water Quality Control Plan (Basin Plan) for the California Regional Water Quality Control Board Central Valley Region, the Sacramento River Basin, and San Joaquin River Basin*. 4th Edition.
- [SWRCB] State Water Resources Control Board. 1995. *Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Estuary*. Adopted May 22, 1995, pursuant to Water Right Order 95-1. Sacramento, CA. 44pp.



**Figure 7-1 Monitoring sites in the Stockton Ship Channel**



**Figure 7-2 Dissolved oxygen levels, Aug 1–Dec 5, 2001**

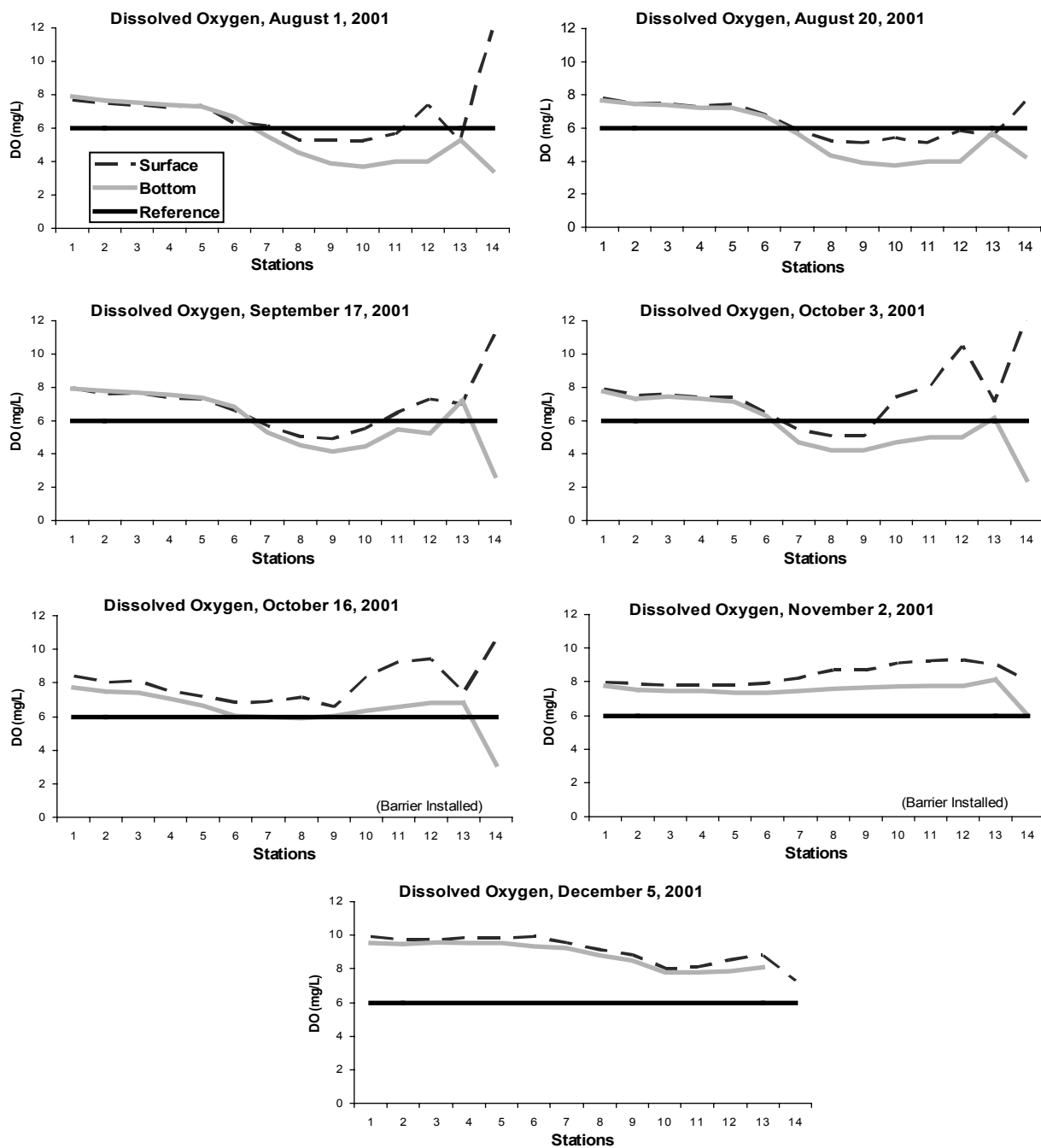
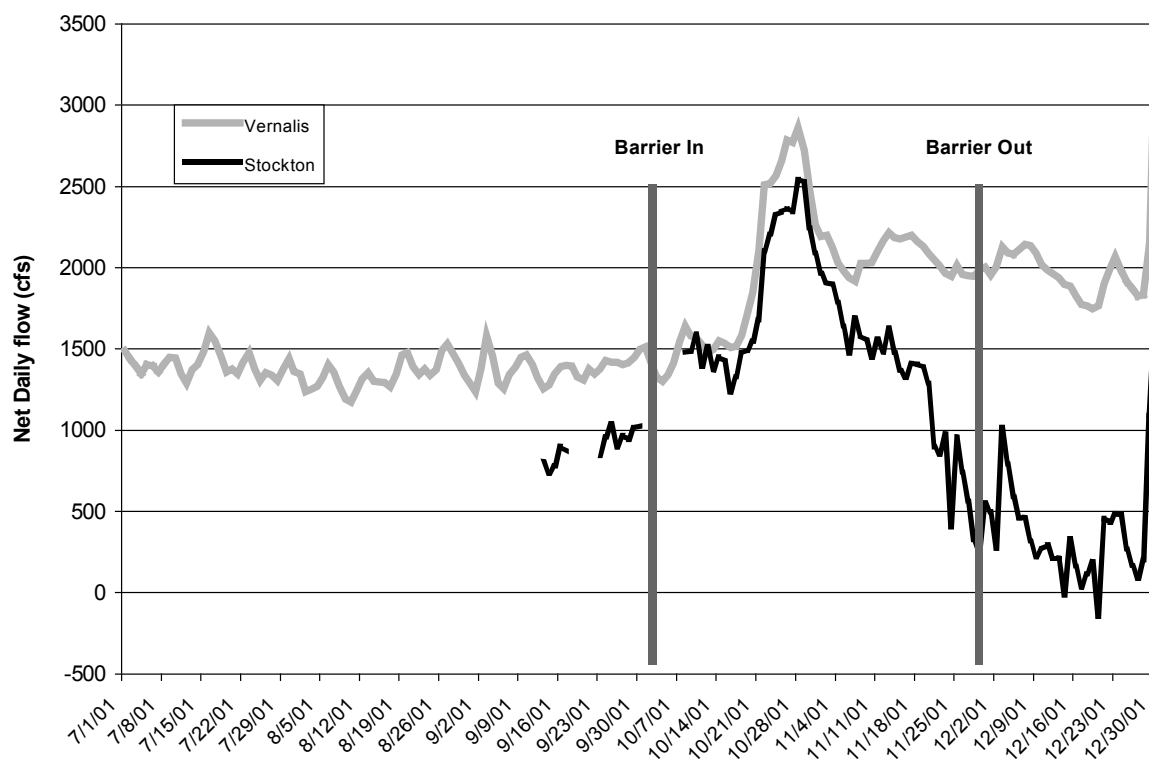


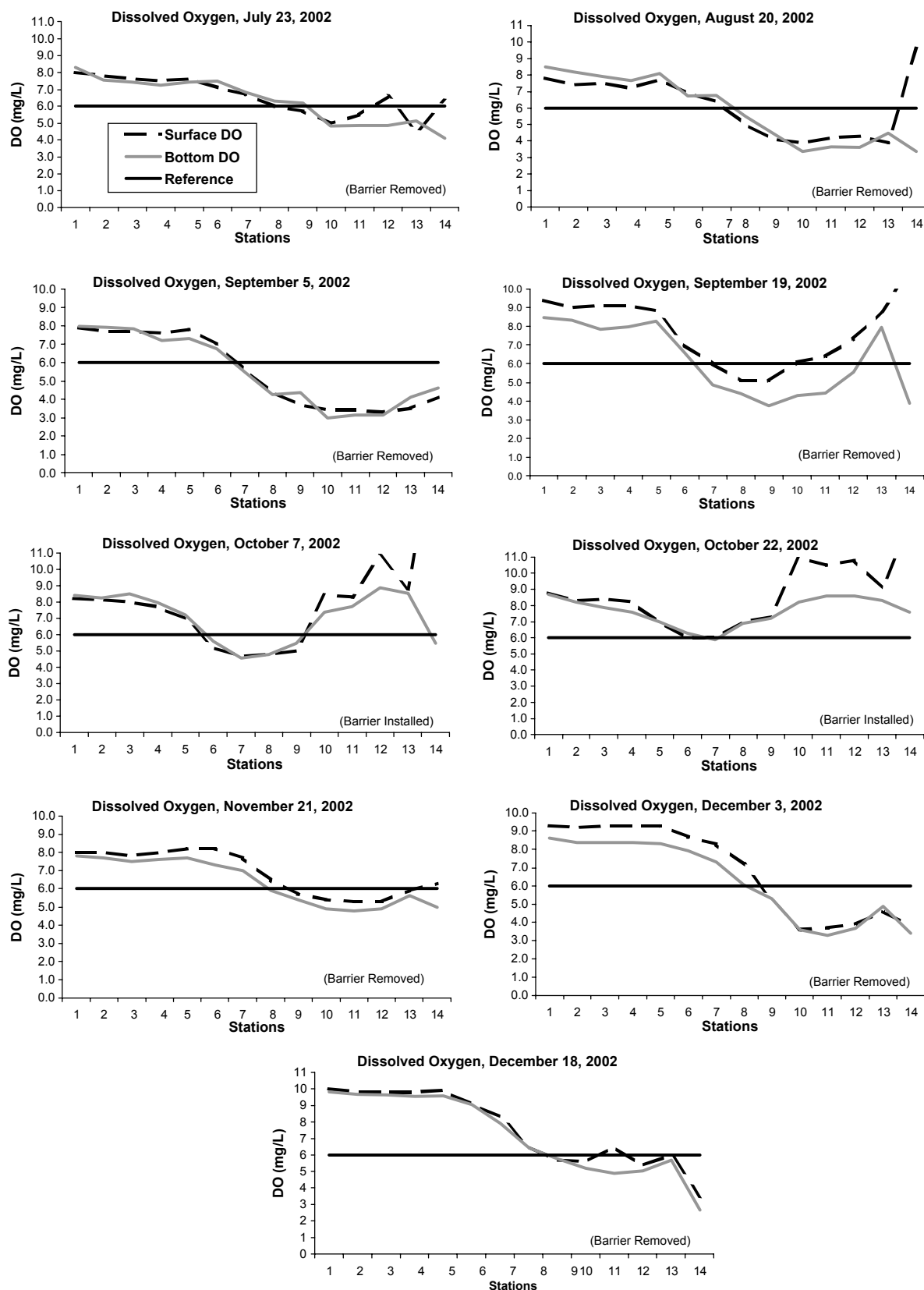
Figure 1 consists of seven subplots arranged in a 3x3 grid, with the bottom-right cell empty. Each subplot shows water temperature profiles for a specific date in 2001. The y-axis for all plots is 'Water Temp. (°C)' ranging from 10 to 28. The x-axis is 'Stations' numbered 1 to 14. Each plot contains two lines: a dashed line for 'Surface Water Temp' and a solid line for 'Bottom Water Temp'. The temperatures are highest in August (top-left) and lowest in December (bottom-center). In all cases, surface temperatures are higher than bottom temperatures, and both show a general decrease from station 1 to 14, with some variability at the end of the profile.

Date	Station 1 (Surface)	Station 1 (Bottom)	Station 14 (Surface)	Station 14 (Bottom)
August 1, 2001	22.5	22.0	26.5	24.5
August 20, 2001	23.5	23.0	26.5	25.5
September 17, 2001	21.0	21.0	24.0	23.0
October 3, 2001	21.0	21.0	24.0	21.5
October 16, 2001	19.5	19.0	20.5	19.0
November 2, 2001	17.5	17.0	17.0	16.5
December 5, 2001	11.0	10.5	11.5	10.5

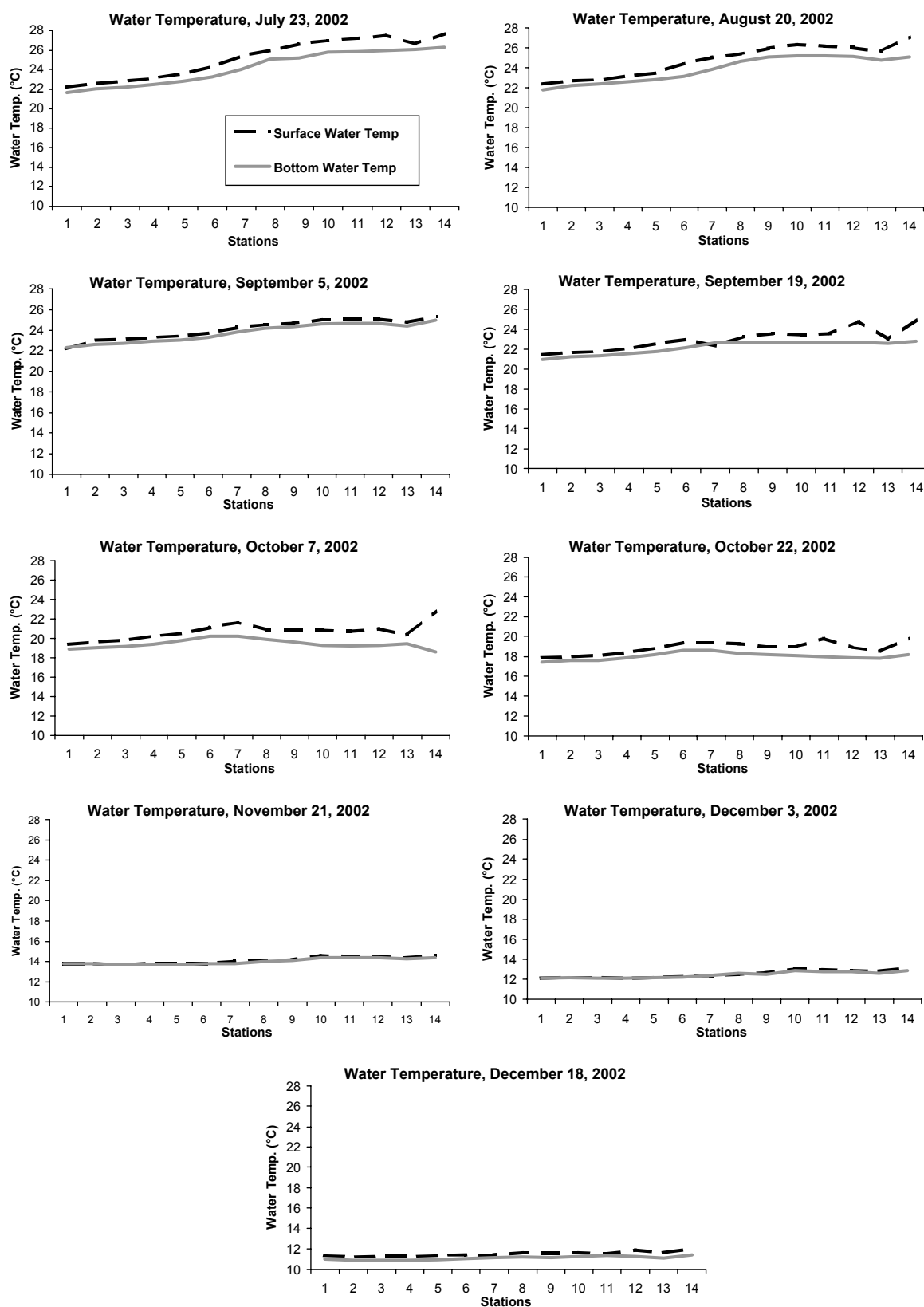
**Figure 7-4 Average net daily flows in the San Joaquin River at Stockton and Vernalis, Jul 1–Dec 30, 2001**



**Figure 7-5 Surface and bottom dissolved oxygen, Jul 23–Dec 18, 2002**



**Figure 7-6 Surface and bottom water temperatures, Jul 23–Dec 18, 2002**





**Figure 7-7 Average net daily flow in the San Joaquin River at Vernalis and Stockton, Jul 1–Dec 30, 2002**

